BERKELEY LAB: A 20-YEAR VISION
ROADMAPS AND KEY NEXT STEPS

Introduction

Contemplating a vision for an institution looking out twenty years is a prodigious task. Much can happen in twenty years, the best we can hope to achieve is to give our impression of how we think the future might develop and where it is that we would like to go. Looking back twenty years is instructive. Nuclear Physics operated the major facilities at Berkeley. Today all that remains of these facilities is a growing list of cleanup tasks. This year the 88-Inch Cyclotron was added to the heap of historical remnants of an earlier age.

As we point the laboratory two decades ahead we must build upon our core strengths. Currently we are described as a multiprogram laboratory. A clear challenge for us is to be more than a collection of programs. We need to create and sustain value from our program diversity, an often undervalued asset that appears in no other scientific laboratory in the country or possibly in the world. Managing this asset begs for an organizational principle that directs our efforts.

We are moving from a multiprogram organization of excellent independent efforts to program "INTERDEPENDENCE." An interdependent organization builds programs around pockets of strength that sustain each other. We must nurture the tissue that binds seemingly unconnected science and technologies together. We would like a story like the following to be told about our laboratory within the next two decades:

At the Department of Energy's Lawrence Berkeley National Laboratory, pixel technology developed in the high energy physics program was used to construct a new imager with higher speed and lower noise performance which is used to make Lowe diffraction measurements of unprecedented resolution at the protein crystallography beamline at the Advanced Light Source (ALS). New protein structural information of extremophiles obtained with this beamline have created a new understanding of molecular machines that form the basis of a computer simulation permitting the design of a synthetic organism that consumes cellulose and produces hydrogen for fueling the hydrogen economy.

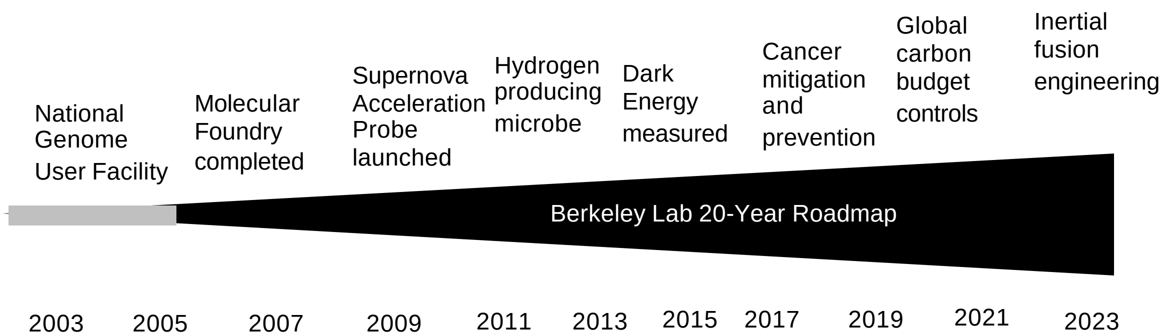
Stories like this should create a new recognition of why multiprogram laboratories should be models for public investing for discovery. This way of thinking should be part of planning and priority setting for the Office of Science.

We have identified seven goals that call on the scientific interconnections at Berkeley Lab:

- Discover the composition of the universe through particle astrophysics and the measurement of dark energy
- Understand and engineer living systems for Department of Energy missions
- Design radically new generations of materials with tailored properties
- Achieve research breakthroughs using soft x-ray and ultrafast science tools
- Enable dramatic discoveries through science-driven computer architectures
- Advance heavy ion driver inertial fusion energy research for high energy density physics and electric power generation
- Understand global climate change and develop carbon sequestration strategies

Achieving these goals will have major scientific and societal consequences. For example, advancing the ability to exploit the extraordinary processes and structures of living systems will improve energy security and prevent cancer and other human disease. Fabricating new generations of materials forged at atomic scale will reduce the environmental impact of manufacturing and gain energy efficiency with advanced technologies. Discovering the origin, composition, and fate of the universe will realize humankind's quest to understand the nature of the earth in the cosmos. Tapping fusion energy will enable a hydrogen economy and source of electricity without greenhouse gas emissions.

The overall roadmap for Berkeley Lab achieves major milestones and goals over a 20-year time period, culminating in understanding the composition of the universe, preventing cancer, control the global carbon budget, and producing electricity through fusion energy. Milestones for the achievement of these goals, and the critical next steps and needs for each program goal, are described in more detail below.



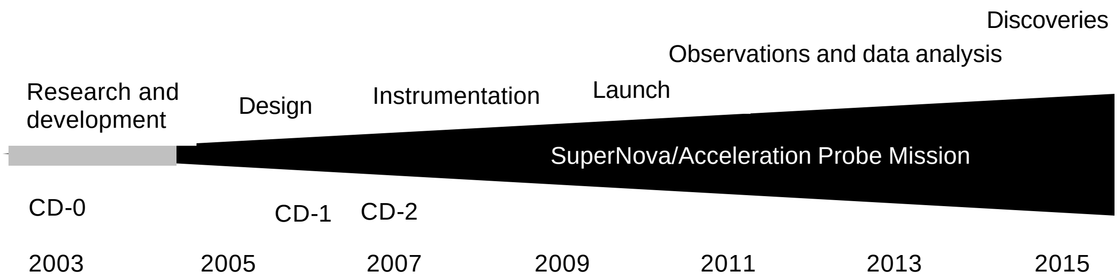
The roadmaps and proposed milestones for achieving the vision are not fixed. The Office of Science (SC) and the Laboratory will annually review the milestones described below, such as during the Department of Energy (DOE) On-Site Review or separate program discussions. This will assure that the roadmaps are aligned with available resources and scientific developments.

Strategic Science Goals and Roadmaps

Goal 1: Discover the composition of the universe through particle astrophysics and the measurement of dark energy.

The discovery that the expansion of the universe is accelerating marks a major revolution in science. The unknown source of energy that powers the acceleration is now one of the greatest mysteries for humankind. Initial calculations indicate that this "dark energy" comprises about 70 percent of the mass of the universe. What is the nature of this unseen dark energy that dominates the universe? Although comprising far less mass, neutrinos are also an important and mysterious component of the universe. The opportunity to measure dark energy and understand neutrinos and related properties of the universe opens new intellectual horizons in the quest to understand the origin and fate of the universe and the relationship of humankind to the cosmos.

The principle path forward for this goal is founded on a SuperNova/Acceleration Probe (SNAP) satellite mission that would measure the dark energy through the observation of distant supernovae with a highly instrumented orbiting telescope. The High Energy Physics Advisory Panel recommended that research on the physics of SNAP (the dark energy phenomenon) should be supported; and the National Research Council report, *Quarks to the Cosmos*, identified this interdisciplinary research area as a high priority for an interagency initiative. The proposed roadmap would expand the SNAP collaboration's research and development effort during the next several years, leading to critical decisions that would establish an Office of Science SNAP Project in partnership with the National Aeronautics and Space Administration (NASA). The roadmap would then consist of fabricating the telescope, instrumentation, and spacecraft; conducting the satellite launch; and followed by several years of observation and analysis.



The FY 2003 proposed progress milestone for the roadmap will be to refine the scope of the SuperNova/Acceleration Probe in pre-project planning and to deliver the requirements for a Critical Decision Zero (CD-0) by the Office of Science. This milestone on the roadmap would deliver the CD-0 information and satisfy readiness requirements.

The FY 2004-2005 SNAP program will focus on developing a conceptual design, the beginning of engineering design, and fabrication and testing of prototypes for the principal SNAP instruments. The milestones of this research and development effort are to produce a draft Conceptual Design Report (CDR) by the end of 2004 and a complete CDR by the end of FY 2005. In the FY 2006-2007 period SNAP will move from the research and development phase to a project status with emphasis on preliminary engineering design and approval of project milestones CD-1 and CD-2. Long-lead procurements for the lightweight telescope, detectors, instrumentation, and spacecraft bus will move into construction during this same time period. The SNAP launch is expected to occur in 2010. Subsequently, data gathering through the supernova observations would measure and characterize dark energy and other parameters of the universe, with results published by mid-decade (2014-2015).

The study of neutrino properties also will contribute to understanding the universe. From recent measurements at neutrino observatories, we have discovered that neutrinos can change their flavor and, therefore, have mass. We now must determine if neutrinos are their own antiparticles and the absolute mass scale of neutrinos. In the long run, accelerator neutrino beams will be needed to resolve the neutrino mystery and determine the neutrino mass. The future program at Berkeley Lab is likely to study neutrinoless double beta decay, reactor measurements of mixing, and accelerator physics directed towards a neutrino source.

Solving the mystery of dark energy and neutrinos will bring about a new era of particle astrophysics and precision cosmology. This science will probe the unknown through developing the observational tools to discover the nature of matter and energy and the evolution of the universe. The dramatic scientific effort will comprehend the universe anew by assembling leading scientific collaborators to focus on the most challenging mysteries in understanding the cosmos.

Key Next Steps: The Laboratory has essentially delivered the requirements for a Critical Decision Zero (CD-0) by the Office of Science, and the SC FY 04 budget includes increased funding for SNAP. The key next step is CD-0 from DOE and Develop SC-NASA framework agreement.

Goal 2: Understand and engineer living systems for Department of Energy missions.

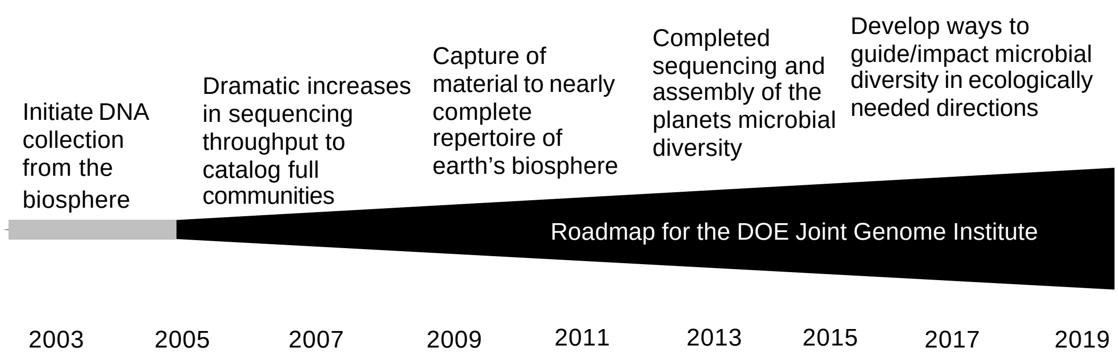
Living systems have evolved remarkable capacities for self-repair, efficiently capturing energy and precisely controlling chemical reactions, adapting to unusual conditions, and performing specialized tasks. The goal of Berkeley Lab's bioscience research program is to discover the detailed mechanisms and systems by which living systems develop, survive, repair and function in different environments to harness and engineer the machinery of cells for Department of Energy missions, with a focus on greatly improved heath, energy security, and environmental restoration.

Berkeley Lab's approach to this major scientific challenge will be highly integrated to leverage all of the Laboratory's scientific, engineering, and computing competencies. High throughput robotic systems for genomics and structural biology will be coupled to a new scale of tools for metabolomics characterization, leading to a new science of comparative physiome biology. A new level of computational biology will emerge, capable of simulating the collective functions of cells and cell systems. A new science of synthetic biology will emerge capable designing micro-organisms and synthetic vesicles capable of destroying human pathogens, sensing and reporting on the environment, capturing energy, and producing new materials. The ability to understand and engineer cell repair systems, differentiate genomic and environmental causes of cell dysfunction will lead to medical breakthroughs including the prevention and cure of cancer and other disease.

Vision for the DOE Joint Genome Institute

Understanding the mechanisms and evolution of life through comprehensive analysis of the genomic structure of world's biota offers tremendous scientific opportunity over the next several decades. A basic foundation of this endeavor and related biological research is to expand the role of the Joint Genome Institute (JGI) to serve as a user facility. It has become clear that high throughput sequencing to advance the nation's science is critically important to ultimately improve human welfare and the environment of the earth. Plans call for a significant fraction of the JGI's sequencing capacity of over 1 billion basepairs to be available as a user service, determined by scientific peer review nominations for DOE sequencing targets. The evolution to a user facility will serve the needs of the consortia of scientists from multiple fields. Importantly in the next 5 to 10 years a variety of areas of research that have not used sequence data will begin to exploit this new and powerful telescope for exploring the biological heavens below our feet, in our seas, and in the air above us. Many Federal agencies will collaborate with the JGI in the sequencing and analysis of a variety of life forms ranging from crop pathogens to environmental indicators. The JGI will enrich the genomic dataset available to the scientific community, placing DOE in the leadership of understanding quantitative and systems biology. An emphasis will be placed on bringing a broad and diverse community, of scientists, including microbiologists, environmental biologists, geologists, physical and computational scientists to work with the JGI to dramatically increase sequencing capacity and efficiency as well as our ability to sample the environment and our ability to quantitatively analyze this data. This will serve as a foundation for strategies of the future to intelligently and positively impact on the environment.

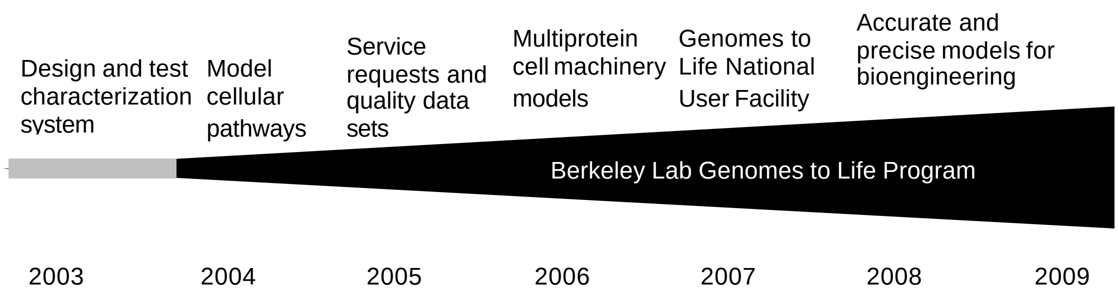
A core activity of the JGI will also be to survey and impact the relationship between the earth's microbial diversity to benefit the environment and other DOE missions. Microbes populate every environment of the earth from superfund sites to boiling ocean vents thousands of feet below the ocean surface. Microbial diversity on the earth is vast and only an infinitesimal fraction of it has been captured. The goals of the JGI microbial diversity and impact program focus on employing the power of sequencing and computational analysis of this data to identify and create a complete catalog of the microbial diversity present throughout the biosphere. Insights drawn from this will enable scientists to utilize microbial diversity to positively impact on the earth's environment. The JGI approach to this crucial scientific challenge will be highly integrated to leverage computing competence of the national labs and associated technology developments to drive the acquisition of genetic material from all regions of the biospheres and to capture and interpret these massive sequence datasets.



Next Key Steps. Planning in concert with the Office of Biological and Environmental Research Berkeley Lab, the Lawrence Livermore and Los Alamos National Laboratories will expand the role of the Joint Genome Institute (JGI) to serve as a user facility. This will enable high throughput sequencing to advance the nation's science. Early planning calls for calls for a significant fraction of the JGI's sequencing capacity of over 1 billion basepairs to be available as a user service. A DOE JGI workshop this summer will help move this effort forward.

Vision for the Genomes to Life Program

Berkeley Lab's Genomes to Life (GTL) program will develop the capability to modify the biochemical activities of microbes through the interpretation of genome-sequence information and experimental characterization of their constituent molecular machines. These objectives will be accomplished by developing a variety of advanced bioinformatics techniques and by using numerous complementary biochemical and biophysical tools to characterize protein/protein assemblies, determine their subcellular location, and learn how cells respond to environmental changes. Ultimately, the program will be able to produce the components of molecular machines, manipulate the machines after assembly, and understand the complex processes that allow assemblies of machines to form cellular systems. Such capabilities will lead to unprecedented opportunities to forge new pathways to energy production, environmental management, national security, and medical diagnosis and treatment.



The Berkeley Lab GTL effort will establish user facilities for functional genomics and metabolomics, high-throughput characterization of biological materials such as protein complexes, and computer modeling. Initially, these facilities can be operated within existing laboratories and will be used to build and test models of how cellular regulatory networks respond to stress. An FY 2003 milestone will be at least one full pass through the GTL characterization system starting with high throughput production and characterization, through an initial level of functional genomic assays, and through integration of this data with the annotated genome of the target microbe. During FY 2003-2004 improved computation and data analysis would identify key molecules and processes in areas of microbial function such as waste decontamination, carbon sequestration, and other important model cellular pathways. This ability, with adequate resources would maximize SC-wide efforts by providing logical guidance on which proteins, experimental measurements of proteomics data, and molecular complexes will be most important. In FY 2004 the experimental facilities will generate quality controlled data on population growth and transcript, protein, and metabolite information on *Desulfovibrio vulgaris* and show progress on *Geobacter metallireducens* and comparison to *Shewanella oneidensis*. Initial pathway reconstructions for the stress response pathways should be completed. Full development of the program will require the construction of a Genomes to Life Facility at Berkeley Lab.

In FY 2005 experimental facilities should begin to show a “service” aspect by rapid response to user requests for material, software, and analyses. Quality controlled datasets and network reconstructions should be available, and the first models should be online. In FY 2006 the experimental facilities will be developed to the point that they are useful user facilities and in FY 2007 they will expand their level of service to meet the full programmatic needs of Berkeley Lab and DOE In addition, the models of the organisms must show good agreement with collected data and the protocols for metal reduction should show informative results. These models can then be applied to scientifically engineering the restoration of contaminated environments. The full development of the user program will require the completion of a Genomes to Life National User facility during the middle of the decade.

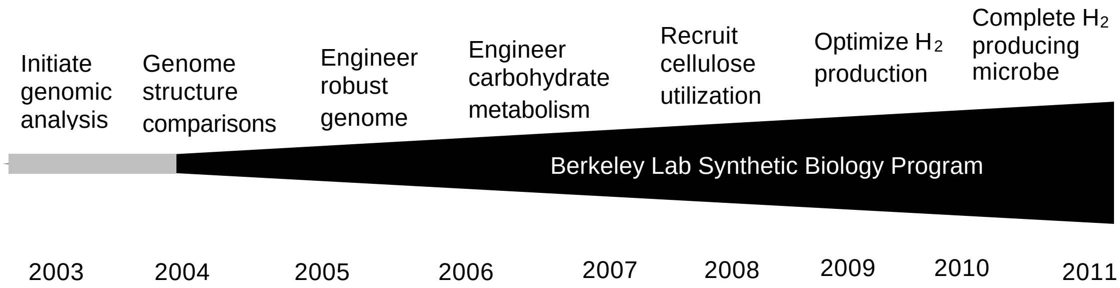
Key Next Steps: The Laboratory will develop a proposal for a National Library of Physiology and Ecology and will follow-up with summary information for the Office of Science on the scientific advances that can be made possible through such a capability. The Laboratory will work with the Office of Biological and Environmental Research and the GTL research community to advance in advancing the vision for the scientific facilities that can enable the GTL program.

Vision for a New Synthetic Biology

Building on the predictive capabilities in cellular understanding provided by the Genomes To Life facilities, the Lab has initiated a broad new initiative in cellular control and design. This new program will expand from the Genomes to Life effort to engineer synthetic organisms and synthetic components such as motile, sensing vesicles.

The first steps to achieve this synthetic biology capability requires focused application programs that will capture information from the core facilities for use in experiments such as the one described below. Twenty years from now, the results of this research could repay the national investment in these facilities with efficient bioconversion of renewable feedstocks into fuels, decontamination of the environment, environmentally benign chemicals production, organisms that can destroy biothreat agents, and organisms that can seek out and destroy tumors. To achieve these results Berkeley Lab is formulating a multidisciplinary research effort dedicated to designing microorganisms. This effort will capitalize on the recently sequenced microbial genomes, the availability of tools to examine and manipulate the molecules of life, a broad base of biological literature and databases, advances in computing power at NERSC, and the extensive human capital present at the Laboratory, and the Joint Genome Institute.

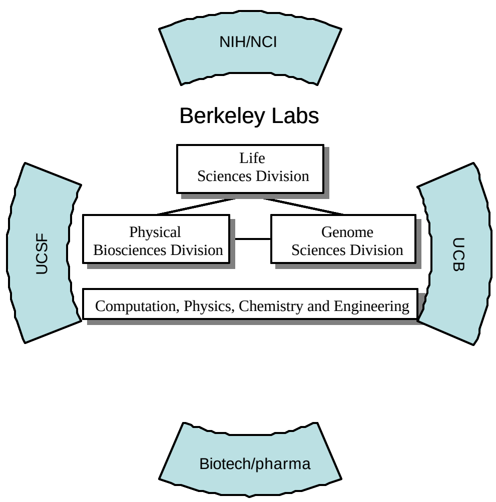
The long-term target for synthetic biology at Berkeley Lab is the development of completely new microorganisms that will convert renewable resources (cellulose, hemicellulose, and lignin) to fossil fuel replacements (hydrogen and bio-diesel). Engineering a completely new cell for energy production necessitates the development of the basic components of a cell (a chromosome and replication system, a cell membrane/wall and its biosynthetic components, macromolecular biosynthesis systems, and basic metabolism) as well as metabolism for renewable resource conversion to fuels. In the short term (1-5 years), we will focus on the development of robust membranes and cell walls that can withstand processing conditions necessary for lignocellulose utilization, construction of a extracellular cellulosome to depolymerize cellulose into usable monomers, the construction of metabolism to convert cellulose monomers into hydrogen, and the construction of a completely new chromosome to harbor all of the genes for the aforementioned capabilities. At the end of the initial 5 year period, we will deliver a retrofitted microorganism that can convert cellulose into hydrogen.



Key Next Steps: The Laboratory will develop a proposal for a Cell Design Institute to conduct the synthetic biology program and to train scientists and engineers. The Institute will establish a common infrastructure for engineering, including automation and screening technologies that scientists engaged in these areas commonly need, and create an organizing framework for large projects directed to particular applications and technology development. The Laboratory will work with the Office of Biological and Environmental Research to advance this effort, which is well coupled to the GTL program. .

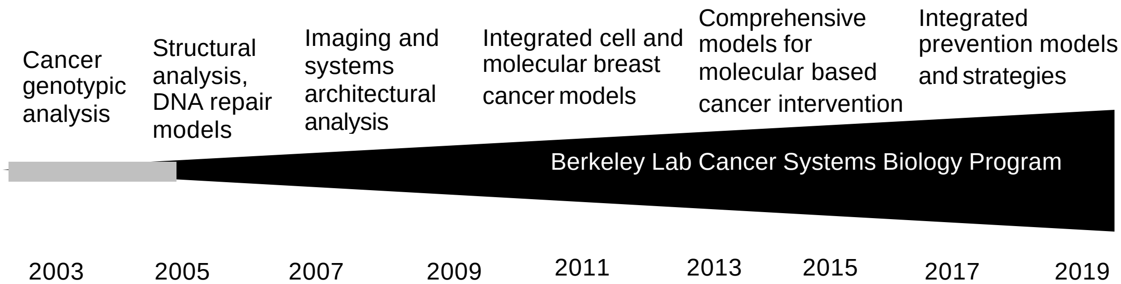
Vision for a Cancer Systems Biology Program

High-throughput genomics and structural biology bring new tools to understanding the genomic and environmental causes of cancer and other diseases. The set of aberrant genes in an individual tumor is the result of an evolutionary interplay between the individual gene composition, stochastic interactions with the environment and chance events during DNA repair. Berkeley Lab is launching a new systems biology program on cancer to understand the genetic, environmental, and biological factors in cancer to reveal how cancers arise and evolve. This information, in turn, will enhance our ability to detect, prevent, and/or treat these diverse diseases.



Understanding these processes is a problem in evolutionary systems biology that requires national laboratory capabilities. The roadmap for the effort will focus on breast cancer models first directed towards identifying genes important in cancer genesis and evolution. The program will seek to understand how the aberrations form, and how collections of aberrant genes interact to produce specific cancer phenotypes. Cell biological models of breast cancer will be developed to reflect the genomic diversity of human cancers, and that enable quantitative assessment of gene function, cell-cell interactions, and molecular evolution. Comprehensive molecular analysis will be conducted many from the JGI, that provide detailed information about cancer genomes and transcriptomes. Structural biology, advancing imaging, and molecular manipulation will reveal mechanisms of DNA repair and provide insights into processes that fail during aging and environmental interactions to trace the mechanisms of cancer development. Computational biology will integrate information from diverse sources to model the molecular behavior of cell systems.

The effort will reveal the molecular mechanisms fail as a result of environmental exposure or natural aging that allow deterministic models of tumor development, and the molecular measures to counter these failures and development of accurate models and protocols for preventing and intervening cancer formation.

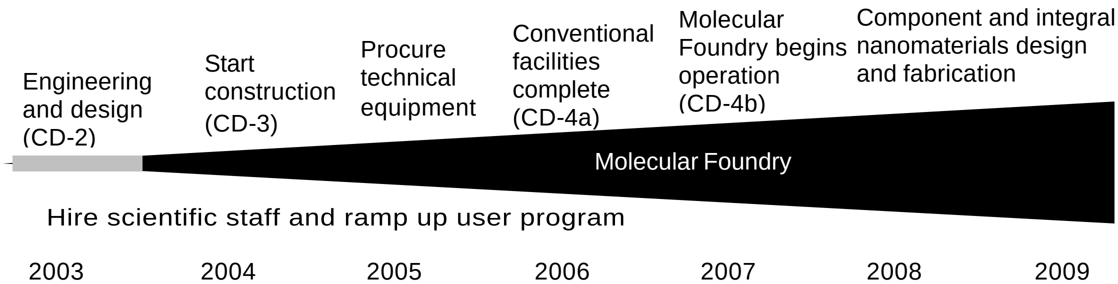


Key Next Steps. The Laboratory will pursue support for beneficial SC/NIH collaborations working with Office of Biological and Environmental Research. We will examine areas of mutually supportive research opportunities, including those involving DOE competencies that can greatly benefit NIH health- and disease-related research. The Laboratory is exploring partnerships, including the University of California at San Francisco and other campuses, to advance the program and its facilities infrastructure.

Goal 3: *Design radically new generations of materials with tailored properties.*

The growth of the economy over the last half century has derived in substantial part from steady improvements in materials technology and biotechnology. Much of this progress has come from advances in electronic materials, magnetic materials, high strength lightweight materials, biomaterials, and biomolecular materials, as key examples. Scientists are now in the early stages of manipulating matter and self-replicating materials systems at the molecular scale, and understanding the behavior of large assemblies of interacting components. These basic science advances will enable industrial progress in new generations of efficient technologies and cleaner production methods needed for economic growth, a quality environment, and energy security.

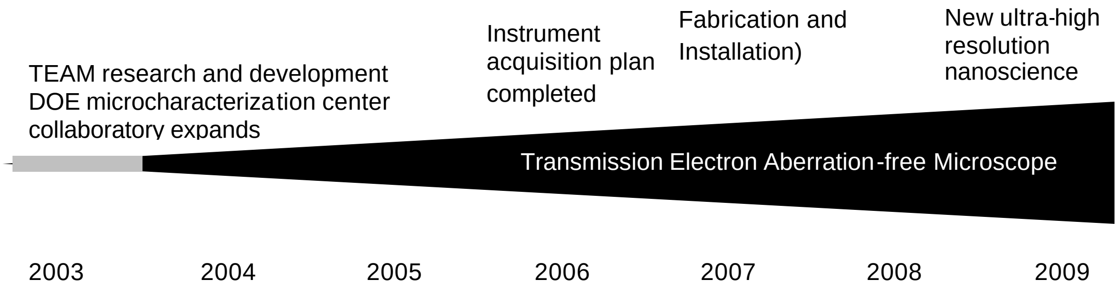
At Berkeley Lab, by 2007 the Molecular Foundry will have been constructed, ushering in a new centerpiece for collaborative nanoscience research, a national user facility dedicated to advancing materials with integrated assemblies of organic and inorganic molecular components. New nanostructured materials components will be developed from research conducted at the Molecular Foundry, including materials with unique properties and new potential designs for devices such as solar cells. In addition, a new Transmission Electron Aberration-free Microscope will have been assembled and installed at the National Center for Electron Microscopy, providing the highest level of atomic resolution for DOE science.



The final outline of the programs for the six user facilities (nanofabrication; inorganic nanostructures; biological nanostructures; organic polymer/biosynthesis; imaging and manipulation; and theory) will emerge in FY 2003. The first few Foundry Postdoctoral Fellows will be hired to set up the facilities in temporary space and begin their research activities. In late 2003 and through 2004, the user program will be established in all six facilities. Some will involve fabrication and synthesis of required nanoscale materials, for example polymers and nanotubes. Others will involve collaborations in research areas across the spectrum of nanoscience. The user program will expand in 2005 when we expect to see the first publications from users and their Foundry staff collaborators. With the opening of the Foundry Building, there will be a significant increase in staff and users. Publications will increase, reflecting collaborations between staff and users as well as among the various facilities, linking the theory and characterization capabilities to the synthesis of both soft polymer and biological nanostructures with the hard lithographic and inorganic materials. The direction of much of this research will be driven by the interests of the users, as described in their proposals to the Foundry.

Further advances in nanoscience will be made possible through a revolution in electron microscopy based on major recent advances in electron optics, detectors, stage design and computing power. These advances make it possible to overcome the fundamental limitations currently imposed by lens aberrations. Under the leadership of Berkeley Lab's National Center for Electron Microscopy (NCEM), the five BES centers for electron beam microcharacterization, located at Berkeley, Argonne, Brookhaven and Oak Ridge National Labs and the University of Illinois are prepared to develop the next generation Transmission Electron Aberration-corrected Microscope (TEAM).

This TEAM instrument will be optimized for 0.5-angstrom resolution in real-time, using both, phase- and Z-contrast imaging techniques. The objective lens geometry will maintain sufficient space in the sample area to allow high angle tilting for nanocrystal structure refinement, three-dimensional reconstruction, and for in-situ manipulation and measurement during atomic-resolution observation. This instrument will also include the ability to perform energy-filtered imaging, holography, highly localized spectroscopy with sub-eV spectral resolution, and fast, position-sensitive nanodiffraction.



Key Next Steps: Molecular Foundry construction is proceeding on track for facility ground breaking in FY 2004. Berkeley Lab is working with the Office of Basic Energy Sciences to ramp up the research program using other facilities to jump-start the nanoscience research program. The Transmission Electron Aberration-free Microscope has received strong support from the Office of Basic Energy Sciences Advisory Committee, and the Laboratory progressing R&D for the instrument.

Goal 4: *Achieve research breakthroughs using soft x-ray and ultrafast science tools.*

Soft-x-ray and intermediate x-ray spectroscopy have made a large impact on many fields: determining the reaction mechanisms of atmospheric pollutants, the structure of advanced magnetic storage media, the chemical reactivity of surfaces and the mechanisms of superconductivity. Soft and intermediate energy x-ray structural studies have revealed the detailed atomic structure of many macromolecular systems, including the entire ribosome, one of the most complicated molecular machines, consisting of 300,000 atoms. The ribosome manufactures proteins by reading genetic code to assemble amino acids. Every living system contains the ribosome: its structural determination will have a major impact on biology and human health.

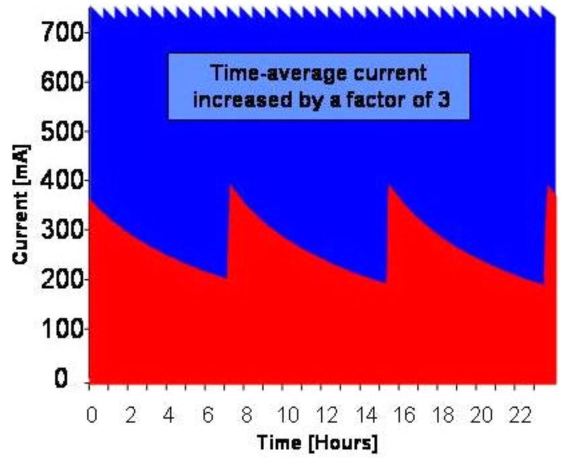
X-ray studies in an ultrafast time regime may yield breakthrough in understanding new approaches to hydrogen research and other approaches to energy production, the processes of photosynthesis, air pollution, and the dynamics of living and nonliving systems. All of these processes rest on events taking place in the femtosecond time scale. Until recently, studies with high-intensity probes in this regime have been beyond the reach of science. Now, phenomena determined by the motion of atoms are open to discovery with major advances in x-ray techniques. X-ray diffraction can provide direct three-dimensional information, and x-ray absorption can provide the radial distribution of atomic positions. X-ray spectroscopy adds details of the electronic configuration necessary to build complete pictures of complex interactions. Combining these techniques with a 20-femtosecond x-ray source will revolutionize many of the fields, including solid state physics, semiconductors, photochemistry, and photobiology

Advanced Light Source Upgrade

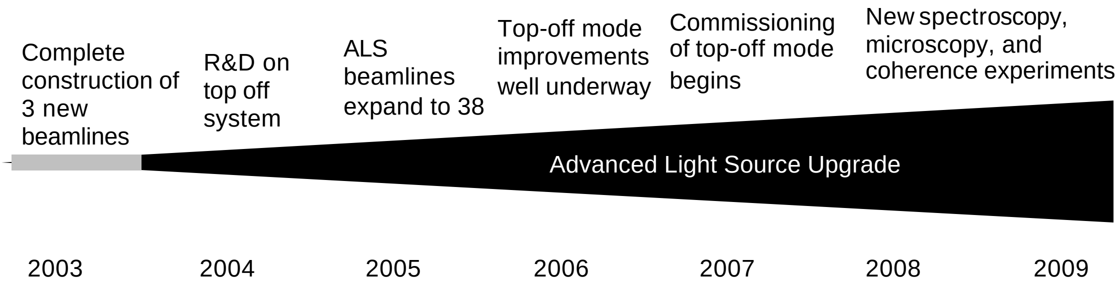
A wealth of advances in soft x-ray and intermediate x-ray research will take place at the Advanced Light Source (ALS) at picosecond time-scale when the ALS upgrades greatly increase brightness, beam life time, and stability. To achieve advances in ultrafast science in the femtosecond regime, and entirely new facility is needed. The design of this new facility, a Linac-based Ultrafast X-ray Source (LUX) has been made possible by

Berkeley Lab's capabilities in reaction dynamics, accelerator science and ALS expertise, and collaborations with the scientific community.

The roadmap for the ALS includes many additional beamlines to take advantage of the scientific opportunities and increases in endstation hours reflecting the beamline growth and the expanding user community. In order for the ALS to keep at the cutting edge in its core areas of high-resolution spectroscopy, high-spatial-resolution soft x-ray microscopy, and experiments that exploit coherence, the roadmap will enhance the performance of the ALS to meet competitive scientific demands and set a new standard for performance.



Achieving several roadmap milestones is necessary for the new level of performance: continuous current fill of the storage ring—"top off mode;" replacing five insertion devices with nine new, narrow-gap, low-emittance undulators, which would also require four additional beamlines. The ALS roadmap would have a tremendous impact on high resolving power for spectroscopy, high spatial resolution for microscopy and spectromicroscopy, high coherence for experiments, and other scientific capabilities.



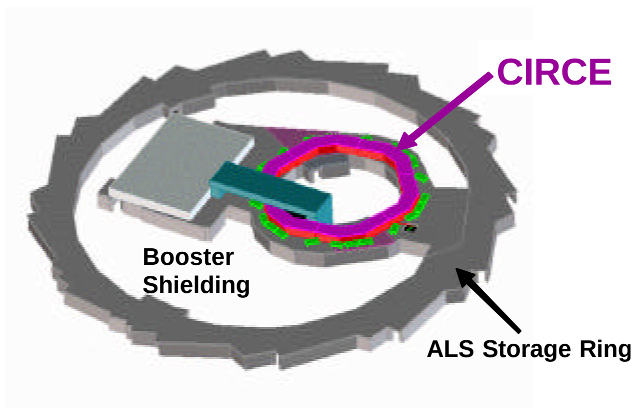
The FY 2003 proposed roadmap progress will be to complete the construction of three new ALS beamlines, expand the endstation hours delivered to users by five percent over FY 2002, and full commissioning of the Molecular Environmental Sciences beamline and the initiation of its experimental program. Preliminary design studies would be undertaken for the top off, undulator and beamline upgrades.

In subsequent years beamlines and endstation hours will continue to grow steadily if funding for planned projects is forthcoming. In FY 2004 an increase in the number of beamlines by another 3 to at least 36 is planned and the commissioning of the SIBYLS beamline will also be initiated. Research and development would be underway on the top off system. In FY 2005 the number of beamlines would increase to 38 and improvements to provide top off mode (with additional funding from BES) would be initiated. By FY 2007 the ALS will increase the number of beamlines to at least 40 and commissioning of top off mode will commence (assuming additional BES funding beginning in FY 2005).

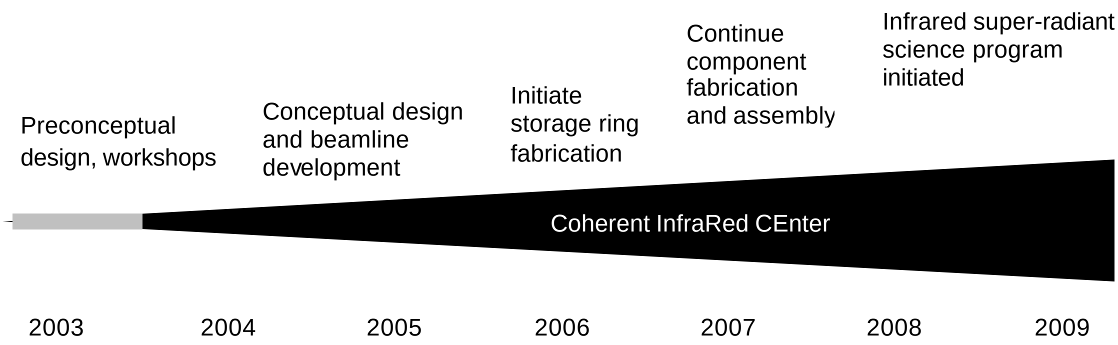
Commissioning of the Ultrahigh Resolution Spectroscopy beamline will commence (with funding for the beamline to be initiated in FY 2004).

Coherent InfraRed CEnter (CIRCE).

Intense infrared radiation sources, many orders of magnitude brighter than current sources, will enable new science and many exciting scientific applications. This science includes low-energy excitations in highly correlated materials, nonlinear dynamics in novel materials, and new medical imaging techniques. The Laboratory can achieve these advances through a small dedicated synchrotron that takes advantage of the property of super-radiance. Synchrotron super-radiance occurs when an electron bunch length is smaller than the emission wavelength. Under these conditions the radiating fields of individual electrons add in phase, producing an intensity that scales with the square of the number of electrons instead of linearly. Experiments at the ALS and at other facilities have demonstrated that coherent terahertz emission produces very high powers, have verified the regime of stability for coherent emission in a storage ring, and have used coherent synchrotron radiation in a ring for measuring the Josephson plasma frequency in a high-temperature superconductor.



A high peak and average power terahertz source is critical for driving and measuring novel non-linear phenomena with excellent signal to noise, and for studying of ultra-fast dynamical properties of materials, both of which are central to cutting edge scientific research and future high-speed electronic devices. It will also be useful for studies of molecular librations and rotations, low frequency protein motions, phonons, superconductor bandgaps, electronic and magnetic scattering and collective excitations in solids (e.g., charge density waves) and provide contrast for a unique types of imaging. The ring design will capitalize on existing ALS infrastructure, such as an existing injection system and user support facilities. The new ring will extend and complement the scientific capabilities at the ALS to create a Coherent InfraRed CEnter (CIRCE).

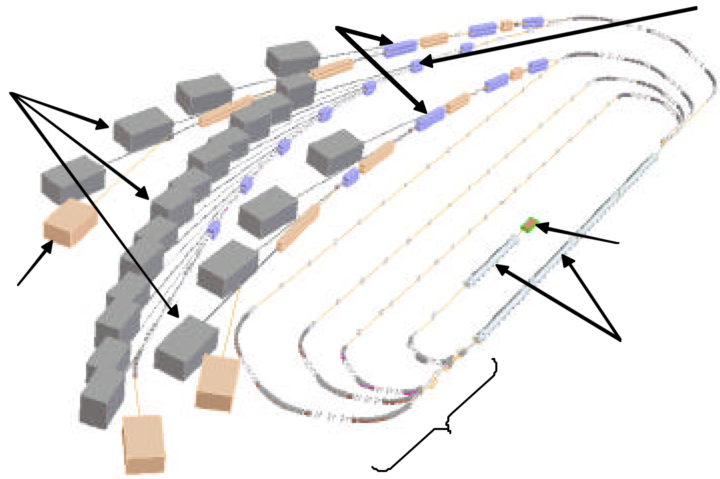


Key Next Steps: Progress to date has included collaboration with the scientific community, research and development and preconceptual design studies. Further workshops are in the planning stages, moving toward conceptual design in 2004 and fabrication in FY 2006 with first light in FY 2008 that will initiate the program on infrared super-radiant science.

Linac-based Ultrafast X-ray Source (LUX)

For ultrafast science, Berkeley Lab has conducted the feasibility studies and preconceptual design for a Linac-based Ultrafast X-ray Source (LUX) that would be a powerful discovery tool for the field of ultrafast science. The prospect of high-intensity, coherent, tunable, synchronized x-rays having durations in the 50-femtosecond range may now open this regime to extremely productive investigation. Over the near term, Berkeley Lab has successfully demonstrated the time-slicing method for producing femtosecond-scale x-rays from bend magnets at the ALS. Progress is being achieved in developing a higher brightness slicing source with a narrowgap undulator at the ALS.

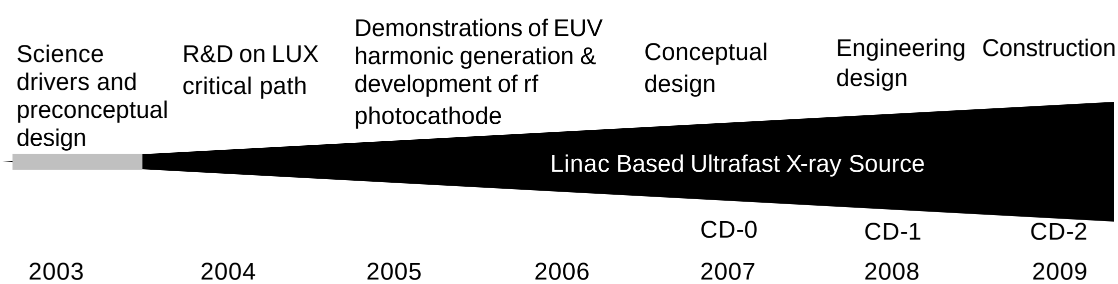
With the scientific community, the Laboratory will further develop the scientific case and perform pre-construction R&D for LUX. The facility will provide high-flux vacuum ultraviolet and x-rays from 20 eV to 12 keV, in pulses as short as 20 femtoseconds in the initial configuration. LUX received encouraging comments in the Basic Energy Sciences Advisory Committee (BESCAC) Subcommittee Workshop Report on 20-Year Basic Energy Sciences Facilities Roadmap, as presenting a strong scientific case and the proposing group was commended for its vision and innovation. LUX follows a decade of ultrafast facility development at Berkeley Lab, and represents the next stage of development following the ALS laser-slicing source under construction.



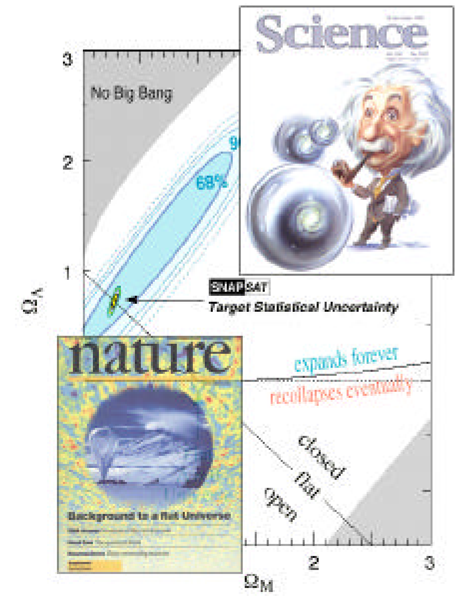
Machine layout showing experimental beamlines cascaded harmonic-generation chains, and major accelerator components. The machine footprint is approximately 150 by 50 meters. A capacity of approximately 20 beamlines is shown, an initial complement of 8 is proposed.

A new era of ultrafast science will emerge from first light at LUX early in the next decade. This science will move the frontiers of science from static observations to revealing the dynamics of atomic and molecular interactions. It will reveal how electron and proton-based interactions occur that underly the chemistry of all phenomena, a regime that has been blind to observation in the past.

Key Next Steps: The Laboratory will host a retreat and workshop to develop and strengthen the science opportunities and user base of the LUX facility, building on a series of science workshops. Development of schemes for cascaded harmonic generation in free-electron lasers, maintaining coherence to nm wavelengths, will be started. During FY 2004-2006 work will continue to gather the national community for ultrafast science at LUX, and critical-path R&D will be addressed, including experimental demonstration of cascaded harmonic generation in the EUV to soft x-ray regime and development of a high-power radiofrequency photocathode gun to provide high-brightness beams at 10 kHz or greater pulse repetition rate. In addition, first x-rays from the ALS undulator ultrafast slicing source will be delivered to the beamline endstation for commissioning and experiments. An ultra-stable optical master oscillator system with phase-locked radiofrequency resonators and laser amplifiers will be demonstrated. In FY 2007 the goal will be to refine the scope of LUX and to deliver the requirements for a CD-0 by the Office of Science.



Goal 5: *Enable dramatic discoveries through science-driven computer architectures.*

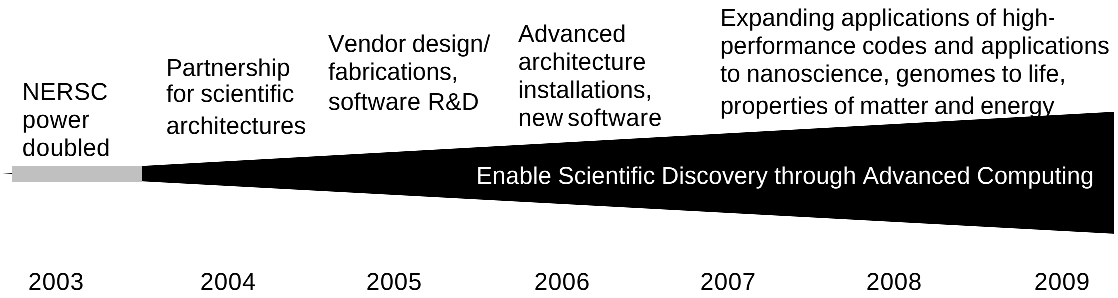


Science inaccessible by other means becomes possible through modeling, such as exploring the interior of stars or studying properties of yet-to-be synthesized materials. Computational science is increasingly central to progress at the frontiers of every scientific discipline critical to SC. Computer-based simulation and data analysis have also transformed science and technology. It is the basis for science that has had a tremendous impact on people's lives and on society: weather prediction, climate change analysis, the design of advanced materials, and the data analysis that made the assembly of the human genome possible. Computational modeling is fundamental to science, whether simulating fluid flow and turbulence or molecular structure and reactivity.

To enable scientific discovery through advanced computing, the roadmap for advanced computing addresses dramatic improvements for simulation and data analysis for scientific applications performance. This performance will critically depend on the architectural characteristics of next-generation platforms. In order to obtain high sustained performance on scientific applications, significant improvements in inter-processor communications bandwidth, reduction in latency, and higher memory bandwidth are required. Data intensive applications will also require new advances in the capability to store, access, and visualize large datasets at the terabyte level.

With existing architecture, Laboratory doubled the power of the National Energy Research Scientific Computing (NERSC) Center computers from five teraflop/s peak capability to ten teraflop/s. The proposed milestone will be NERSC computer operations in full production, delivering 82 million massively parallel processor (MPP) hours to the user community in FY 2003, and 100 million MPP hours in FY 2004.

To address the challenging science to be achieved beyond the current generation architecture, Berkeley Lab is now joining with other laboratories and in partnerships with computer manufacturers to develop a new generation of architectures tailored to scientific applications. These new architectures offer the promise of the most powerful data analysis and simulations possible, addressing DOE scientific demands including those coupled to complex simulations for high-resolution climate-change models, advances in materials science for nanoscience, new fusion demonstration and simulation projects, the challenge of dark energy, and other major SC opportunities.



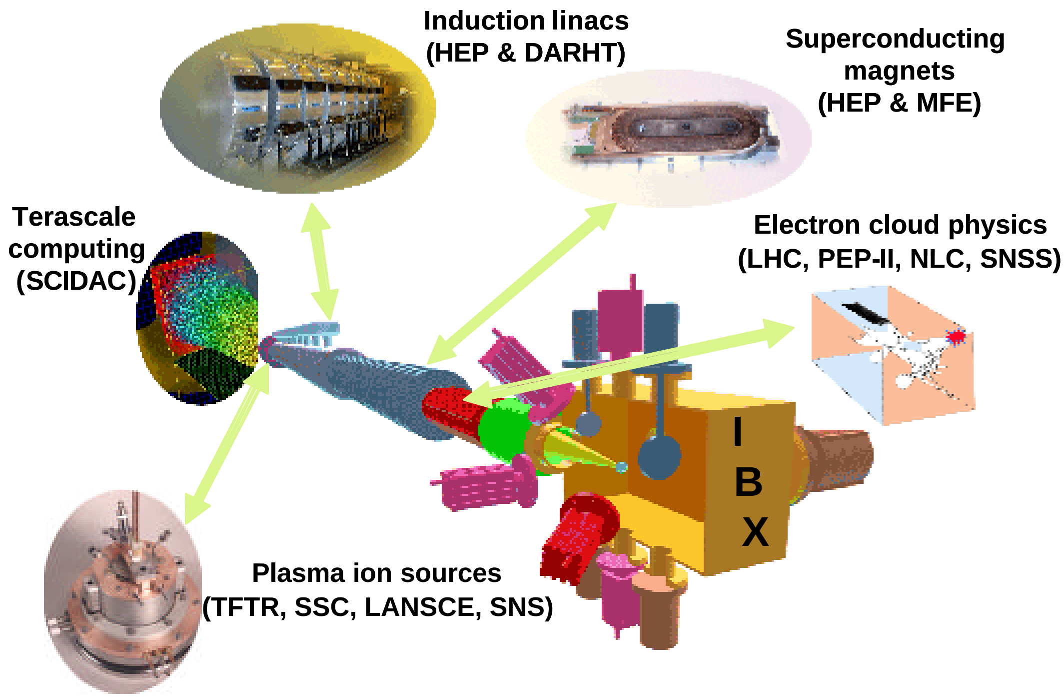
Key Next Steps: In FY 2004 the Laboratory will also be measured on successful progress in planning with other Laboratories and with computer vendors to advance the development of scientific computing architectures and the software systems to enable their research exploitation. This collaboration will enable Berkeley Lab to address the scientific demands with a new architecture and software that can yield high cost-effectiveness with unprecedented levels of performance, high memory bandwidth, and low-latency interconnections. The effort will lead to the installation of computing capabilities at NERSC and other DOE sites in the hundred to two hundred teraflop/s range in FY 2006, employing the new architectures with the software systems that advance the scientific applications (performance will depend on the level of enhanced budget).

Goal 6: *Advance heavy ion driver inertial fusion energy research for high energy density physics research and ultimately, for electric power generation*

We are working towards advancing high energy density physics and the potential long-term power production through inertial confinement fusion that would be free of greenhouse gas emissions. The Heavy Ion Fusion (HIF) Virtual National Laboratory, consisting of Berkeley Lab, Lawrence Livermore National Laboratory, and Princeton Plasma Physics Laboratory, is formulating the next generation of studies to advance this science and ultimately deliver fusion power for the nation. Heavy-ion fusion accelerator research addresses the physics of the production, acceleration, compression, and focusing of intense heavy-ion beams, for their use as drivers for inertial-confinement fusion systems.

Intense ion beams, if compressed to short enough pulses and delivered to small enough focal spots, can provide an important new tool for exploring high energy density plasmas. This is because of the unique energy deposition property of ion beams, namely, that in very dense plasmas compared to the beam ion density, ions are observed to slow down in straight-line trajectories. At high energies, the ion range can be large compared to the optical mean-free-paths in solid-density plasmas, allowing ion energy deposition to be well-inside experimental targets. The deep penetration of high-energy ion beam heating allows more flexibility in some types of targets that can be used for dense plasma science.

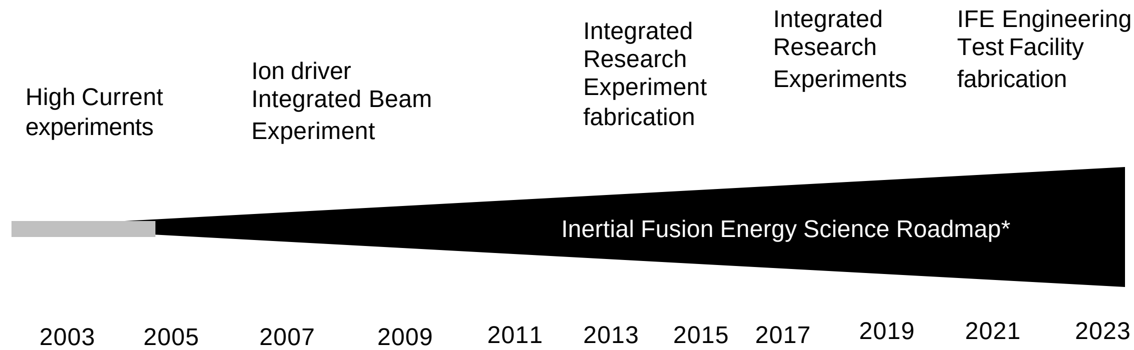
In advance of dense plasma science research, three experiments currently underway are studying new sources and initial acceleration of heavy ion beams, accelerator transport limits, and the complicated neutralization and focusing of the beams. The next important step will be to integrate the beam manipulations from source-to-final focus into a single experiment. Since changes to the beam-distribution function accumulate through each phase of the driver, it is important that such an Integrated Beam Experiment (IBX) would be able for the first time to test focusing of a beam that had experienced all the processes of a driver. The IBX will validate the key physics of high current beams for high density physics and for heavy-ion-driven inertial fusion by providing integrated source-to-target beam transport and compression, followed by focusing to the spot sizes necessary for target physics. The IBX will enable investigation of intense beam physics inaccessible in any other facility, including study of longitudinal stability and wave physics, electron instabilities and their effect on focusing, halo production, longitudinal compression,



neutralization, and focusing. These investigations will determine the limits of compression and focusing of ion bunches into the smallest possible target volumes. Understanding these limits is essential to enable future, larger heavy-ion accelerators to drive either inertial fusion targets or high energy density plasma targets to study dense plasma at more extreme states of 100 eV and 10 Megabar pressures. These experiments would be important both for heavy-ion fusion as well as for high energy density plasma science.

The IBX will provide well-diagnosed beam data essential to benchmark and improve the physics used in the development of a terascale integrated computational beam model, which in turn will optimize the designs for all future experiments and for power plant drivers. A preconceptual design for the IBX can be ready for physics validation review by the Fusion Energy Sciences Advisory Committee by early FY 2005 or earlier.

Subsequent to fabrication of the IBX and as an outgrowth of its experimental program design, an Integrated Research Experiment would be designed. Also at the beginning of the next decade, pre-conceptual designs of an Integrated Fusion Energy power plant could be developed. Based on the results of the Integrated Research Experiment, an Engineering Test Facility (ETF) and its experimental program, an accelerated schedule could result in a demonstration power plant based on modifications to the ETF. Although the current plan reviewed by Fusion Energy Sciences Advisory Committee (FESAC) calls for completion of the demonstration power plant by the year 2035, an accelerated schedule as a "stretch" goal, with completion of a demonstration plant by approximately 2030 is possible. An even more aggressive schedule may be technically feasible but is dependent on the resources available for fusion energy research.



The effort at Berkeley Lab leverages accelerator science, engineering, and computational science. Expertise in induction linacs has been instrumental to Berkeley Lab's ability to deliver an advanced induction electron linac for the Dual Axis Radiographic Hydrodynamic Test Facility at Los Alamos National Laboratory, an effort sponsored by Defense Programs, which takes advantage of developments originating in the fusion energy science program.

Key Next Steps. The Laboratory is preparing an integrated High Energy Density Physics Research Plan for further discussion with the Office of Fusion Energy Science. An IBX preconceptual design can be ready for validation by FY 2005 or earlier

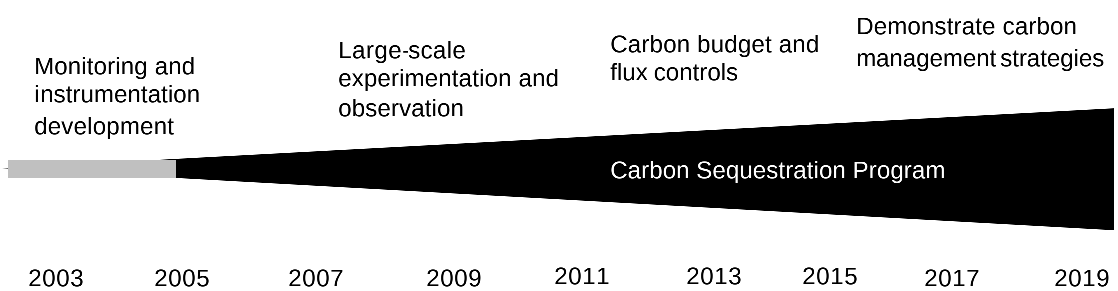
Goal 7: *Understand global climate change and develop carbon sequestration strategies.*

Berkeley Lab works in partnership with national laboratories and universities to improve global climate modeling and to advance the science of carbon sequestration. New research on ocean carbon sequestration in partnership with Livermore Lab and other institutions is pursuing fundamental research on ocean sequestration, including the assessment of the effectiveness and consequences of ocean fertilization and carbon dioxide injection. The effort includes a combination of *in-situ* experimentation and observations in key oceanic regimes and through numerical simulation of the ocean carbon system.

Another proposed strategy to reduce the build-up of greenhouse gases in the atmosphere is to capture carbon dioxide from large point sources, such as fossil-fueled power plants, and sequester it in the deep underground. Geologic formations such as oil fields, coal beds, and aquifers are likely to provide the first large-scale sinks. Study of geologic sequestration of carbon dioxide is carried out using SC developed scientific capabilities in concert with DOE's Fossil Energy Program through the Berkeley Lab-led GEO-SEQ Project. This is a joint study with Lawrence Livermore and Oak Ridge National Laboratories, along with twelve industrial and academic partners, to investigate the feasibility and collateral benefits, for the long-term storage of carbon dioxide in depleted oil and gas reservoirs, brine formations, and coal beds.

The program conducts and manages a set of targeted, interrelated, applied research and development tasks includes developing the information about the location and capacity of suitable geologic formations, and developing the analysis protocols for the technologies for carbon dioxide separation, compression, transportation and sequestration. In addition, the effort will increase the effectiveness and safety of geologic sequestration by demonstrating cost-effective and innovative monitoring technologies and will enhance methods to predict and verify that long-term sequestration is safe and effective. The effort will work to establish Regional Carbon Sequestration Centers, including one in California.

These sequestration centers address the challenges posed by the diversity of carbon dioxide sources, geologic sinks, and technology options present throughout the United States. Development of sequestration-based enhanced oil and gas recovery will be the early focuses for the California Center. The centers will work to achieve large-scale demonstrations with industrial partners to develop commercially viable sequestration technologies, with field demonstrations once again providing proof of concept. Widespread deployment of this technology throughout the globe, together with improved energy efficiency and power production technologies, offers the prospect of controlling the global carbon budget by the end of the next decade.



Key Next Steps. The Laboratory has prepared brief white papers on the ocean carbons sequestration plans and on geologic carbon sequestration. The Laboratory will work with the Office of Biological and Environmental Research and the Office of Fossil Energy to advance the DOE carbon sequestration research program.

Integrating Research to Advance DOE Missions

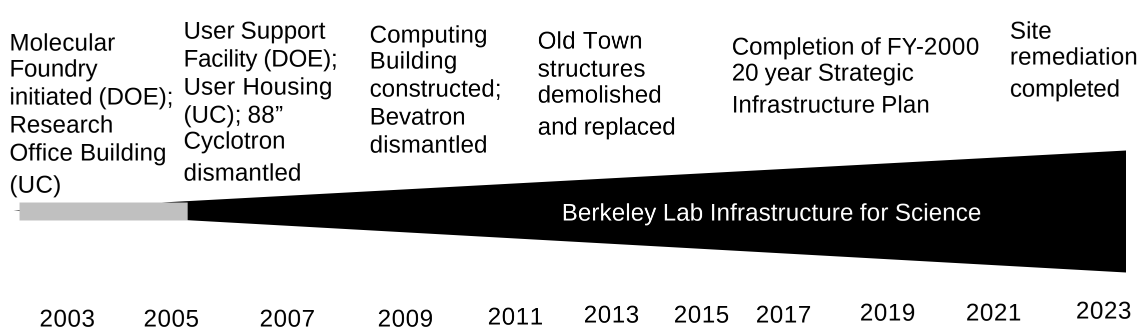
Progress on these goals directly complements the breadth of the Laboratory's research programs conducted for DOE. All programs at Berkeley Lab and sister laboratories in the Office of Science system benefit from advanced computing architectures and the new levels of performance in the hundred teraflop/s regime. Advances in detector research for SNAP have value for other programs needing broad-spectrum, high-resolution imaging in radiation intense environments. Nanoscience will have impacts on chemistry, condensed matter physics, and cell and molecular biology. Soft x-ray and ultrafast science will enable detailed spectroscopic analysis, new levels of dynamic analysis, as well as unprecedented spatial resolution for progress in many fields.

Berkeley Lab's integrated capabilities will serve DOE programs that improve the energy security of the nation while reducing environmental impacts. For the Office of Civilian Radioactive Waste Management, the Laboratory will further apply computational resources, engineering and field science to develop the coupled transport models and data that support the analysis of Yucca Mountain as the nation's nuclear waste repository. We are working with DOE's Office of Energy Efficiency and Renewable Energy to further develop the most advanced energy-efficiency and -reliability technologies and computational models, often in partnership with industry. We will continue our work with national organizations and the State of California to reduce energy demand and improve electricity-distribution reliability. We are investigating the next generation of energy-efficient technologies for carbon dioxide emissions reduction.

Site Infrastructure for Science

To sustain the Laboratory's integrated science efforts, the nation needs to invest in the science infrastructure that underpins discovery and the advancement of DOE missions. The Laboratory will fall far short of its scientific goals if the infrastructure of previous generations is relied upon for a new generation of science. Working with the Office of Science, The Laboratory is committed to building the user infrastructure necessary for our national scientific facilities. We have allocated significant Laboratory resources to infrastructure, for example, completing the Users Mezzanine of the ALS, and extending its photon flux energy into the intermediate x-ray regime. We are working with third parties to construct a new research office building and to address the needs for a user dormitory.

The Laboratory must join with DOE, and the scientific community that relies on the physical and natural sciences to further address space and other infrastructure needs of the growing user base as well as other facility needs. The Molecular Foundry will be a key resource for the National Nanotechnology Initiative. In addition, the Office of Science must sustain its support for dismantling the Bevatron following its illustrious scientific career. The proposed closure of the 88-Inch Cyclotron, a distinguished facility for the low-energy nuclear science community, must be accompanied by the resources for dismantling and deconstruction. The overall goal is to achieve the replacement and new construction of facilities identified in the Laboratory's Strategic Infrastructure Plan.

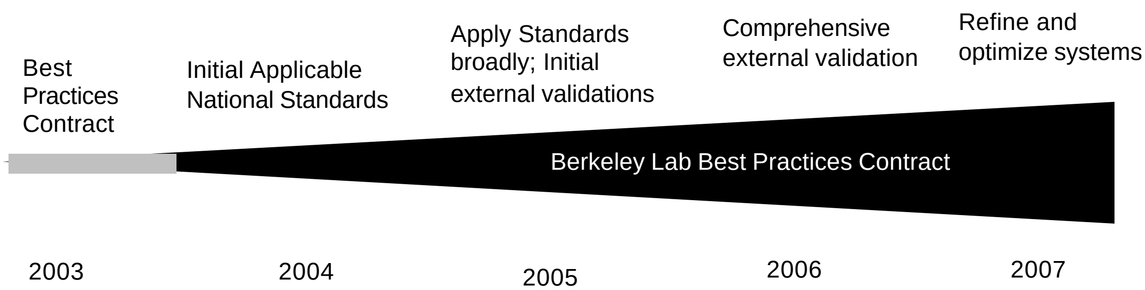


Key Next Steps. The Laboratory has prepared cost estimates for the dismantling and deconstruction of the 88 Inch Cyclotron and is working with the Office of High Energy and Nuclear Physics and Laboratory Infrastructure division to develop a path forward for funding the dismantling activities. The Science Laboratory Infrastructure Program is critical to the Laboratory: the User Support Building is a priority project for FY 2005, and progress on budget planning for a construction start is underway.

New Best Practices Contracting and Accountability

The public must have confidence in the Office of Science stewardship for American investments in science. We are working to keep that trust through robust management that holds managers and staff accountable for results, in the full letter and spirit of the President's Management Agenda. We place high value on creativity, integrity, best business practices, and a safe and secure working environment. We take the steps needed to assure the security of information, and are recognized for the quality and effectiveness of our cybersecurity monitoring program.

Our business systems must be robust and accountable to the highest standards of public review. With DOE, the science strategic goals and business systems have been forged to support the Under Secretary of Energy's principles for Office of Science contracts. We will first apply national standards to our work practices and evaluations. Certifications will be validated by external and independent experts, leading to comprehensive application of externally validated evaluations. We seek to refine and strengthen effective roles and responsibilities of DOE and contractor personnel, their behaviors, and their expectations.



Through effective management we will achieve our vision to serve as an institution where creative people collaborate to tackle the most challenging problems of our time. This can only be achieved through partnerships with DOE scientific leadership, the national scientific community, and collaborating national laboratories.

Key Next Steps. The Laboratory will work with the Berkeley Site Office and DOE Headquarters to implement Best Practices Contract and Principles for the management and operation of Berkeley Lab.